The Building Systems Approach To Acceptable Indoor Air Quality

A Review and Analysis of OSHA RFI Docket H-122: "Occupational Exposure to Indoor Air Pollutants"

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This paper presents an analysis of what has come to be known as the "building systems approach" for the prevention and mitigation of poor indoor air quality (IAQ). Supporting data for the analysis provided in this text were obtained through a review of the public comment submissions to the OSHA RFI Docket on Indoor Air Pollution (H-122).

The review of the RFI docket on indoor air included all public comments received by OSHA through April of 1992. Consideration was given to all "substantive" comments, i.e., comments which included either references to the published literature on IAQ or to observations about indoor air quality. Opinions which were not supported by data, experience or even anecdotal information were not considered "substantive," and were excluded from consideration.

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Overview: The Building Systems Approach is Based Upon the Proper Design, Operation, and Maintenance of a Building's HVAC System.

The building systems approach to achieving and maintaining acceptable indoor air quality emphasizes attention to the proper design, operation and maintenance of a building's heating, ventilation and air-conditioning (HVAC) system. The approach is advocated by a substantial number of respondents to the OSHA RFI, representing such diverse groups as governmental agencies (Wisconsin Dept. of Industry and Labor, 3-10; Kansas Dept. of Human Resources, 3-1094; University of California, 3-1192); labor unions (the AFL-CIO, 3-1185; Food and Allied Services Trades, 3-434; Am. Fed. of State, County and Municipal Employees, 3-446; Int. Fed. of Professional and Technical Engineers, 3-770); professional organizations and trade associations (the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), 3-440; the Business Council on Indoor Air (BCIA), 3-933; the National Energy Management Institute (NEMI), 3-1183; the Tobacco Institute, 3-1086; the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), 3-856; the National Environmental Development Association's (TIEQ), 3-1054); IAQ monitoring and mitigation experts (T.D. Sterling and Associates Ltd. (TDSA), 3-1073; Healthy Buildings International (HBI), 3-1053; Gershon Meckler Associated, 3-879; Alan Hedge, 3-955; James Woods, 3-745; Eagle Environmental Health, 3-500; Terracon International, 3-501), and product manufacturers (Philip Morris, 3-1074; R.J. Reynolds, 3-1087; Johnson Controls, 3-1102 and Dow Chemical, 3-502).

In its simplest terms, the central focus of the building systems approach is upon appropriate ventilation, which, in turn, includes provisions for adequate outdoor supply air and its distribution to occupied spaces. The intended effect of this focus is to decrease exposure to substances in indoor air and to prevent and/or alleviate complaints about indoor air quality. (BCIA, 3-933; Dow, 3-502) This is a performance-orientated, "engineering systems" approach which requires the inter-disciplinary expertise of architects, mechanical engineers, HVAC contractors and maintenance engineers.

The approach recognizes the existence of potential "significant risk" and/or "material impairment" from worker exposures to poor indoor air quality, as documented by literally thousands of building investigations completed in the past decade. It acknowledges that individual causes of complaints related to indoor air quality in "problem buildings" are rarely identifiable, and that suspected causes of poor indoor air quality are likely to be multi-factorial, involving any number of substances at low-exposure levels, as well as comfort-related factors such as air movement, temperature, lighting and humidity. (TDSA, 3-1073; HBI, 3-1053; NEDA-TIEQ, 3-1054; Hedge, 3-955)

The approach offers a comprehensive solution to poor indoor air quality. Adequate supply air intake and its distribution serve to dilute and/or remove a wide range of potential substances in the indoor air, including volatile organic compounds (VOC's) such as benzene and formaldehyde, carbon monoxide (CO), carbon dioxide (CO_2), constituents of environmental tobacco smoke (PTS), radon, biologicals, etc. (ASHRAE, 3-440; NEMI, 3-1183; PM, 3-1074) This solution remains constant as the work activities of building tenants and the "mix" of substances in indoor air change over time. The effectiveness of the building systems approach is adequately supported by data in the published literature, and will be discussed at length below. (See: "D. Ventilation: The Mitigation Procedure for Poor IAQ.")

The buildings systems approach is also a *feasible* solution to indoor air quality problems and to the maintenance of acceptable indoor air. The approach relies upon already existent technology and standards for the design, operation and maintenance of HVAC systems. It is likewise a *cost-effective* solution, because any costs associated with compliance with the approach are likely to be small and offset by a reduction in complaints and a potential increase in worker productivity. (TDSA, 3-1073; PM, 3-1074; BCIA, 3-933; Woods, 3-745; Ventresca, 3-941) The approach directs resources to controlling the widest range of potential substances in indoor air.

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The Scientific Basis For the Building Systems Approach

The basic tenets of the building systems approach are:

(A) Indoor air quality problems are most often associated with inadequate HVAC system performance, including incorrect system design (improper sizing, modification and/or installation), inadequate outside air intake, poor filtration and/or inadequate preventive maintenance of the system; (Eagle EH, 3-500; NEMI, 3-1183; HBI, 3-1053);

(B) Complaints regarding unacceptable indoor air quality (usually associated with symptoms of irritation, annoyance and discomfort) cannot, as a rule, be directly traced to specific airborne substances or to levels of exposure; (TDSA, 3-1073; PM, 3-1074; Hedge, 3-955; HBI, 3-1053);

(C) A number of environmental factors unrelated to IAQ may also contribute to complaints about indoor air quality. These include temperature, humidity, lighting, noise, and physical "stressors" such as workload, job satisfaction and general ergonomic conditions; (Hedge, 3-955; TDSA, 3-1073; NEDA-TIEQ, 3-1054; NEMI, 3-1183; AFL-CIO, 3-1185);

(D) Remediation and mitigation of poor indoor air quality, and the attainment and maintenance of acceptable indoor air quality, depend upon the correct design, operation and maintenance of a buildings' HVAC system. (ASHRAE, 3-440; BCIA, 3-933; NEMI, 3-1183; HBI, 3-1053).

The basic premises for the building systems approach are directly supported by data from over 2,000 individual building investigations conducted by governmental and private agencies in the U.S. and Canada. These building investigation reports are included in eight large independent databases on "sick-building syndrome," and can be found in the published literature on IAQ. (PM, 3-1074)

The individual sick-building databases exhibit remarkable similarities in their reported results. IAQ complaints in roughly one half (or more) of the building investigations have been related to inadequate ventilation. An additional (and often substantial) percentage of the complaints reported in the investigations have been associated with poor HVAC maintenance, including poor filtration and contaminated systems. Specific airborne substances have been identifiable as "causal factors" for complaints in fewer than 20 percent of all building investigations.

Inadequate Ventilation is Associated With Approximately Half of All Complaints in Sick-Building Cases

Building investigation reports in the published literature fall under the heading of "sick-building syndrome" investigations, wherein complaints of irritation and discomfort (e.g., headaches, eye, nose, and throat irritation, dizziness, shortness of breath, mental fatigue, drowsiness, and lethargy) are reported, and IAQ specialists/building investigators are asked to determine potential causal agents and possible remedial actions. (Eagle EH, 3-500; HBI, 3-1053; TDSA, 3-1073; AFL-CIO, 3-1185)

One of the most notable compilations of building investigations was undertaken by NIOSH and referenced in the OSHA RFI (*Fed. Reg.* 56(183), September 20, 1991). Inadequate ventilation was identified as a primary problem in fifty-two percent of the 484 building investigations in the NIOSH database. Inside contamination was identifiable in only fifteen percent of all buildings; microbiological contaminants were identified in five percent.[1,2] (PM, 3-1074)

A database of 1,362 building investigations compiled by Health and Welfare Canada also identified inadequate ventilation as the primary problem in 52 percent of the buildings investigated. Specific indoor air contaminants were identified in only 12 percent of the investigations.[3,4] (TDSA, 3-1073; PM, 3-1074)

Public Works Canada, another Canadian federal agency, investigated 30 buildings for IAQ complaints between

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1987 and 1990. Ventilation-related problems were reported in one half of the buildings.[3] (TDSA, 3-1073)

TDSA Ltd. have compiled data on 408 building investigations conducted in the U.S. and Canada. The results have been analyzed and computerized in what is called the "Building Performance Database." Ventilation-related inadequacies were directly associated with IAQ complaints in 49 percent of the buildings catalogued in the Building Performance Database.[4] (TDSA, 3-1073)

A private, U.S.-based IAQ monitoring firm conducted 412 sick-building investigations from 1981 through 1988. Ventilation problems were associated with complaints in 62 percent of the buildings investigated; bacterial and fungal contamination was reported in nearly a third of all buildings investigated. (HBI, 3-1053)

A 1989 report by Dr. James Woods assessed 30 cases of "problem buildings" investigated by the Honeywell Corporation since 1986. Woods' research indicates that 75 percent of the buildings investigated had inadequate outdoor supply air intake. Similarly, 75 percent of the buildings exhibited inadequate air distribution to occupied spaces, and 65 percent of the buildings suffered from inadequate HVAC maintenance.[7] (Woods, 3-745; PM, 3-1074)

Kim (1990) summarized 105 investigations of problem buildings undertaken by Clayton Environmental Consultants, a IAQ monitoring firm in the U.S.[8] (Morey, 3-505) She wrote:

> In a survey of 105 buildings, Clayton found that 53 percent had [HVAC] maintenance problems, 49 percent had operational problems (such as improper handling of control equipment), and 33 percent had design problems. Mechanical engineers evaluated the HVAC systems in 70 of the buildings, in which they found that 75 percent had maintenance problems, 70 percent had operational problems, and 47 percent had design problems. Of the 105 buildings, 95 were sampled for contaminants. Of these, 28 were found to have problem levels of microbial contaminants, 26 had volatile organic compounds and 13 combustion products. (PM 3-1074)

Freund et al. from the New Jersey Department of Health evaluated 221 complaint buildings in that state and reported that 43 percent were associated with inadequate ventilation.[9] (HBI, 3-1053)

The Oregon Department of Resources submitted results of 36 state office building investigations to the OSHA RFI (3-1157). The respondents observed:

> Thirty-six state office buildings were examined for IAQ problems. Significant problems were found in 16 buildings. Many of the problems were associated with inadequate ventilation and high levels of carbon dioxide . . . studies in Oregon have shown that when outside make-up air falls below 15 cfm, complaints increase.

In a submission to the OSHA docket by Local 12/ Occupational Illness Support Group of the U.S. Department of Labor, the authors report that:

> Inadequate ventilation is the primary cause of most of the indoor air quality problems . . . . This is a result of the Department's inability to maintain adequate amounts of outside air . . . . (3-1017)

Published data from a number of sick-building investigation databases reveal that deficiencies in ventilation have been directly related to complaints about IAQ in one half or more of all reported cases. HVAC-related problems have been associated with as many as 75 percent of the complaints in several of the sick-building databases discussed above.

Significant Risk Associated With Poor IAQ: Poor IAQ in the Workplace is a Widespread Problem; Data from Building Investigations Indicate a Significant Risk of Impairment for Non-Industrial Workers Associated With Poor IAQ; Costs to Employers and Workers

In 1982, the World Health Organization described a complex of eight symptom groups which could be used to characterized sick-building syndrome (SBS). Those symptoms included: irritation of the eyes, nose and throat; dry mucous membranes in skin; erythema; mental fatigue and headache; cough; wheezing; nausea

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and dizziness; and hypersensitivity reactions. (TDSA, 3-1073) In addition, SBS has also been characterized by complaints of discomfort which do not precisely fit any of the WHO's eight categories, e.g., "stuffiness," chills, unpleasant odors, etc. (Hedge, 3-955)

Building Related Illness (BRI), as indicated earlier, describes infirmities of known cause which are often traceable to sources of microbial contamination in the building or to the transmission of infectious respiratory disease. Although specific, documented cases of BRI are rare in comparison to complaints about poor indoor air quality, there is perhaps little doubt that BRI poses a potential significant risk for workers in the non-industrial workplace. Support for this statement can be derived from the sick-building syndrome databases. For example, Public Works Canada identified microbial problems in 16 percent of the 30 buildings they investigated.[3] Robertson of HBI reported allergenic fungi in 34 percent of buildings investigated and allergic or pathogenic bacteria in 9 percent of the buildings. (HBI, 3-1053)

The submission to the OSHA RFI docket by TDSA Ltd. includes an estimate of between 26,000 and 116,000 annual cases of sporadic Legionnaires disease in the United States. (TDSA, 3-1073) Other kinds of communicable and non-communicable building-related infections exist, ranging from hypersensitivity pneumonitis to the flu. However, data to support a precise numerical projection of total cases are apparently not available.

Symptoms of irritation and discomfort reported in thousands of sick-building syndrome investigations strongly suggest the existence of an additional potential significant risk of "impairment" for non-industrial workers. Sick-buildings, of course, constitute only a subset of the total non-industrial workplace building stock in the United States. Nevertheless, the World Health Organization and others have estimated that SBS may affect as much as 30 percent of all buildings in the U.S., which in turn may affect 20-30 percent of the non-industrial workforce. (Woods, 3-745)

The AFL-CIO has estimated in its response to the OSHA RFI that indoor air pollution may effect "30-70 million building occupants and between 800,000 and 1,200,000 commercial buildings in the United States . . ." (AFL-CIO, 3-1185) A substantial number of other respondents to the OSHA RFI provide estimates of risks attributable to poor IAQ, which are summarized in Appendix I of this document.

Poor indoor air quality also imposes additional costs upon employers and workers alike. Such costs include those related to health and the costs of lowered productivity, stemming from greater absenteeism, loss of concentration, etc. Although such purported costs can only be estimated from the available data, respondents to the OSHA RFI contend that they are indeed substantial — perhaps amounting to billions of dollars annually. (BCIA, 3-933) (For a complete analysis of costs attributed to poor IAQ by respondents to the OSHA RFI, see Appendix II.)

Data on BRI and SBS thus verify the potential significant risk posed by poor IAQ on the non-industrial workforce in the United States. Potentially burdensome costs to the American employer and worker alike are similarly associated with incidents of BRI and SBS.

IAQ Complaints Generally Cannot be Associated With Specific Airborne Substances

The OSHA RFI on Indoor Pollutants sought information and data on a number of substances potentially associated with complaints about IAQ. These substances include: volatile organic compounds (VOC's), biologicals, passive tobacco smoke (PTS), carbon monoxide (CO), carbon dioxide (CO_2), and radon. (For a review of the RFI docket submissions which discuss these substances, see Appendix III.) A review of the docket indicates that while these substances are often mentioned as potential "causes" of poor IAQ, few data exist which suggest that *specific* substance exposures have been associated with *specific* complaints. Moreover, the databases on sick-building syndrome support the contention that specific airborne substances rarely are identifiable as sources of IAQ problems or complaints. A number of comments in the RFI docket substantiate the above claims. For example:

The Atlantic Richfield Company (ARCO) reports that, in their experience, "when monitoring has been

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conducted, hazardous contaminants have either not been detected, or they are present in concentrations far below those known to present health hazards." (ARCO, 3-448)

The submission from Organization Resources Counselors states that:

> Companies report monitoring for formaldehyde, total and respirable particulates, total organics. . . . In almost all cases where monitoring was done for specific contaminants, results were either below the level of detection, or were below OSHA Permissible Exposure Limits. (3-1084)

Similarly, CanTox, Inc. reports that:

> More than half (63 percent) of the compounds detected in indoor air could not be attributed to a definite source. The largest group with known sources were found to have multiple sources and their presence could not be exclusively attributed to one specific source. This clearly has significant implications with respect to attempting to use source control to maintain indoor air quality. (3-1180)

The American Federation of Government Employees (AFGE) of the AFL-CIO reports that "unfortunately, despite the substantial evidence linking poor indoor air quality to AFGE members' adverse health effects, AFGE is unable to obtain the data needed to make the causal connection between specific contaminants and those adverse health effects." (3-529)

United Technologies reports that, "based on our experience in occupational settings and knowledge of the professional literature, there are only very weak data that directly relate specific chemicals to IAQ." (3-651)

TDS and Associates Ltd. report, after citing four studies, that:

> The correlation between symptoms presented in IAQ complaints and causative agents is weak because exposure to many different types of contaminants in indoor air, originating from both indoor and outdoor sources, has been shown to result in similar health and comfort complaints. The presence of pollutants in indoor air, combined with thermal comfort parameters of temperature and humidity, and other building characteristics, such as ventilation, lighting, noise and occupant density and activities, make it difficult to isolate the causative agent and IAQ related health and comfort complaints. (3-1073)

The American Industrial Hygiene Association (AIHA) notes that, based on their experience:

> In most IAQ complaints, symptoms are non-specific and could be caused by a variety of factors. Correlations can be found where there is a consistent spacial and temporal relationship and the complaint can be resolved by changing the building condition. Biological contamination may sometimes be distinguished by a pattern of allergy symptoms. (3-735)

The Philip Morris submission to the RFI docket cites a study by Canadian researchers that reported results of a building investigation in which temperature, humidity, dust, nicotine, formaldehyde, volatile organic compounds, and CO_2 were measured.[18] Occupants of the building complained of poor indoor air quality, and a questionnaire evaluation revealed a substantial number of complaints about unsatisfactory thermal conditions, dry air, drowsiness and eye irritation. However, all measured parameters, including temperature and humidity, were within accepted comfort exposure guidelines. The authors were unable to correlate any single measured environmental parameter with complaints or symptoms. They concluded that their investigation "showed that complaints reported by occupants were associated with perceived rather than measured levels of indoor environmental parameters." (PM, 3-1074)

The Building Performance Database compiled by T.D. Sterling and Associates Ltd. provides data on airborne substance monitoring from well over 200 sick-building investigations. Average recorded levels of carbon dioxide, carbon monoxide, respirable suspended particles, formaldehyde, airborne fungi and bacteria, nicotine, and temperature and humidity, are all within parameters of "acceptable" exposure. (See Appendix IVa.) Nevertheless, the buildings from which the monitoring results arose were deemed "sick." The authors conclude: "In general, IAQ investigations of white collar workplaces have found indoor concentra-

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tions of measured substances far below occupational exposure levels. . . ." (TDSA, 3-1073)

PTS Workplace Exposures: The SBS Databases Reveal that PTS May Be Directly Associated With Complaints in Only Two to Four Percent of All Investigations; Data from Workplace Exposure Studies on PTS Constituents Indicate That Typical Nonsmoker Exposures to PTS are Minimal and Often Below Analytical Limits of Detection

Because it is visible and easily identified by its aroma, passive tobacco smoke (PTS) is often initially identified as the cause indoor air quality problems. However, data submitted to the OSHA RFI on actual workplace exposure levels to PTS constituents, together with conclusions derived from several major databases on sick-building syndrome, indicate that tobacco smoke is rarely the underlying *cause* of complaints about poor indoor air quality. For example, in HBI's database of 412 sick-buildings, ETS was reported to be a significant contributor to complaints in only 3 percent of all buildings investigated. (HBI, 3-1053) In the sick-building database compiled by TDSA Ltd., smoking was implicated as a major contributor to complaints in only 12 of 408 (less than 3 percent) of the buildings surveyed.[6] (TDSA, 3-1073) NIOSH investigated more than 200 "sick-buildings" through 1984 and reported that tobacco smoke was a source of claimed discomfort in only 2 percent of the buildings investigated.[1] (PM, 3-1074) In a summary of 94 building studies by government investigators from Health and Welfare Canada, complaints were attributable to indoor constituents such as photocopy machine emissions and PTS in only 5 percent of the buildings investigated.[3] (PM, 3-1074) In all of the databases, inadequate ventilation was determined as the underlying source of complaints in over half of all investigations.

It is nevertheless understandable, given the easy recognition of PTS, that persons experiencing sick-building symptoms initially tend to blame PTS. Indeed, researchers have indicated that the mere visibility or presence of tobacco smoke may provoke claims that PTS is the cause of reported symptoms and complaints.[11,12] This is likely to be especially true when an individual is already feeling discomfort in a SBS setting. (PM, 3-1074) However, as one commentator has pointed out: "Removing the smoker entirely, then, would not effect health and comfort problems in 95 to 98 percent of sick-buildings."[13] (TDSA, 3-1073)

Moreover, published data submitted to the RFI docket on the contribution of PTS constituents to overall ambient air levels in typical workplaces suggest that such contributions are minimal and often indistinguishable from contributions from other sources.[14] (ORNL, 3-499; TDSA, 3-1073; Reasor, 3-1071; Holcomb, 3-1065) Of course, data from monitoring studies on PTS-related constituents in the workplace are varied and depend on a number of factors, such as the number of smokers present, activity levels, ventilation, total volume, etc. (See Appendix IVb.) Nevertheless, it is possible to observe trends in the data. For example, after a review of 37 supporting studies from the published literature, Philip Morris reports that:[15-51]

> . . . [T]here is little difference in ambient levels of carbon monoxide in smoking and nonsmoking areas of workplaces and public places and in homes with and without smokers. Other studies indicate that PTS contributes approximately 30 percent of the total particles in the air of a typical public place. Nicotine is often used as marker for PTS exposures because it is unique to tobacco smoke. Typical measurements of nicotine range from an exposure equivalent of 1/100 to less than 1/1,000 of one filter cigarette per hour. This means that a nonsmoker would have to spend from 100 to 1,000 hours or more in an office, restaurant, or public in order to be exposed to the nicotine equivalent of a single cigarette. (3-1074)

Philip Morris also observes that "studies which have examined PTS constituent levels of nitrosamines, nitrogen oxides and volatile organic compounds (such as benzene) report minimal contributions to overall ambient air levels in homes, the workplace, and public places."[26,28,44-51] (3-1074)

In the most comprehensive review and analysis of the literature on ETS exposure published to date, researchers from Oak Ridge National Laboratories (ORNL) observe that "it has been difficult to discern the effect

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of CO from ETS in any situation except extreme conditions of experimentally designed exposure."[14] (ORNL, 3-499)

The ORNL monograph on ETS also reports that "indoor concentrations of NO, NO_2, or NO_x can be somewhat elevated when compared to outdoor background, but show very little dependance upon the presence of ETS." The authors also note: "It has been difficult for many studies to demonstrate consistently elevated levels of formaldehyde due to ETS."

The ORNL monograph also reviews and discusses studies on the measurement of tobacco smoke particles (RSP's) in the workplace which have employed UV/PM (ultra-violet particulate matter) methods of analysis. Studies indicate the following RSP contributions from ETS; e.g., (1) 131 offices—27 ug/m3; (2) 22 offices—32 ug/m3; (3) 194 offices—28 ug/m3; and (4) 31 offices—44 ug/m3.

The ORNL monograph concludes that:

> Studies of offices, restaurants, train compartments, and public buildings suggest that ETS contributes to the indoor air burden of VOC's but that other sources predominate. Major sources include building materials, furnishings, cleaning products, office machines, gasoline, and combustion sources associated with cooling, heating, and transportation. (ORNL, 3-499)

Other respondents to the OSHA RFI reach similar conclusions. Dr. Mark Reasor, after a review of over 25 published studies, concludes that "ETS is unlikely to contribute significantly to daily workplace exposures to volatile organic compounds, carbon monoxide, oxides of nitrogen, polycyclic aromatic hydrocarbons, and nitrosamines," and that "it may influence exposure to nicotine and to respirable suspended particulates, but under adequate ventilation conditions, this exposure is likely to be low." (Reasor, 3-1071)

The submission by Theodor D. Sterling and Associates, Ltd. reports results of PTS constituent monitoring in workplaces undertaken by TDSA.[16,22,42] The data indicate the existence of extremely low levels of nicotine — sometimes at or below the detection limits of the analytic method — and concentrations of RSPs ranging from 10 to 50 ug/m³. RSP levels reported in nonsmoking workareas were low (17-20 ug/m³), and there were no significant differences reported between areas that did or did not receive ventilation air recirculated from smoking lounges. (See Appendix IVb.) (TDSA, 3-1073)

Professor Alan Hedge of Columbia University reported the results of his study on 4,479 office workers from 27 air-conditioned offices. Hedge examined the potential impact of smoking and smoking policies on reports of sick-building syndrome. With the exception of slightly elevated levels of nicotine in non-smoking offices adjoined to smoking areas, monitoring results for various PTS constituents revealed no significant differences in workareas where smoking was permitted compared to workareas where smoking was not permitted. (Hedge, 3-955)

HBI submitted data from their study of 585 offices in which various PTS-related constituents were monitored.[41] (HBI, 3-1053) Aside from increased airborne levels of nicotine in smoking offices, the levels of ETS-related constituents reported in typical smoking and nonsmoking areas were statistically indistinguishable. For example, the average level of carbon monoxide in 254 nonsmoking offices was 3.1 ppm; the average for 331 smoking offices was 3.4 ppm. Similarly, the average level of particulates (RSP ug/m³) recorded for 331 offices in which smoking was permitted was 46 ug/m³. The average for 254 nonsmoking offices was 20 ug/m³. The authors note that these "real-life respirable particulate particle levels averaged about four times lower than the Repace and Lowrey model predicted, at 46 ug/m³." They also observe that the average levels of particles in both smoking and nonsmoking workareas were substantially less than the level designated as "Limited or No Concern" (100 ug/m³) by the World Health Organization's "Consensus of Concern for Tobacco Smoke Particles."

Thus, a review of the scientific data on exposure levels to ETS in the workplace, together with analyses of those studies provided by respondents to the OSHA RFI, indicate that typical workplace levels of ETS constituents cannot be associated with a significant exposure risk to nonsmoking workers.

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PTS: Reports of Chronic Health Effects in the Workplace are not Supported by the Available Epidemiologic Data

The scientific literature reporting measurements of PTS constituents in indoor air provides little support for claims about possible chronic health effects among nonsmokers in the workplace. Moreover, the available data from published epidemiologic studies on the workplace do not provide sufficient support for the claim that PTS exposure in the workplace is associated with chronic disease in nonsmokers. (See Appendix III; 3. PTS.)

A primary deficiency in the epidemiologic studies on PTS is the lack of reliable exposure data. Published epidemiologic studies which report associations between spousal smoking and chronic disease (e.g., lung cancer, heart disease, etc.) in nonsmokers are not based on actual exposure assessments for ETS. Instead, these studies rely on subjective responses to questionnaires to assess "exposure" rather than on any quantifiable measurement. Questionnaire inquiries regarding "spousal smoking" or "living with a smoker" are used as surrogate determinants for ETS exposure in these studies. Recent studies indicate, however, that such subjective assessments are an extremely unreliable and inaccurate measure of exposure.[52] Furthermore, questionnaire responses about exposure often vary widely when compared with actual measurements of ETS constituents in the workplace.[53]

Lung Cancer

The argument that PTS exposure increases the risk of lung cancer in nonsmokers is based on an interpretation of the data from epidemiologic studies of nonsmoking women married to smokers (spousal smoking). Of the 33 published epidemiologic studies on the issue of spousal smoking and lung cancer, none actually *measured* exposure to PTS. Moreover, twenty-seven of the 33 studies report results which are not statistically significant overall — that is, their conclusions were consistent with the null hypothesis of no association between reported exposure to PTS and lung cancer in nonsmokers. Most important, however, is that fourteen of the published spousal studies also assessed reported *workplace* exposures to ETS via questionnaire (although no actual measurements were conducted).[54] Twelve of the 14 workplace studies report associations between ETS and nonsmoker lung cancer which do *not* achieve statistical significance. Only two studies report marginally statistically significant increased risks for persons who reported exposure to ETS in the workplace.

Heart Disease

There are no studies in the published literature which have examined actual ETS exposures in the workplace and heart disease in nonsmokers. Only twelve epidemiologic studies on spousal smoking in the home and heart disease in nonsmokers are available. These studies, based on marriage to a smoker, are not directly relevant to the workplace issue. In addition, the spousal smoking studies on heart disease contain no data on actual exposures to ETS. Instead, exposure estimates are derived from questionnaire responses.

Nonetheless, five of the 12 published epidemiologic studies on spousal smoking and heart disease did attempt to address workplace exposures to ETS.[55] None of these studies reported a statistically significant increased risk of heart disease among nonsmokers claiming exposure to ETS in the workplace. Thus, the existing literature does not provide support for the claim that ETS exposure in the workplace is related to an increase in risk of heart disease among nonsmokers.

Respiratory Disease Other Than Cancer/Asthma

Few studies have examined the issue of exposure to ETS in the workplace and respiratory disease (other than cancer) in nonsmoking adults.[56] The studies that have been conducted on this issue have reported contradictory results. Researchers who have reviewed these studies have cited problems with the methodology utilized and have pointed out that confounding factors (e.g., other exposures) were not considered.[57]

Data on the possible association between ETS exposure and increased risk of an asthmatic reaction are similarly inconsistent. There are ten major studies on the possible association between exposure to ETS and acute respiratory symptoms in adult asthmatics.[58] The studies are inconsistent in their reported results which range from reported decreases in pulmonary function to no acute respiratory effects among asthmatics

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exposed to ETS. The studies that do report an association between adult asthma and exposure to ETS suffer from several methodological flaws that include: (1) confounding factors that are not adequately controlled for in many studies; (2) inadequate sample sizes; (3) psychological factors that have not been ruled out; and, (4) reliance on unrealistic exposure conditions in enclosed smog chambers.

Thus, the available published epidemiologic data on reported PTS exposures in the workplace and various chronic disease endpoints in nonsmokers do not support the claim that PTS poses a significant risk for chronic disease among workers. This is not to deny that some individuals may nevertheless report annoyance or irritation by the sight or smell of PTS. The building systems approach to achieving and maintaining adequate indoor air quality is designed to address those kinds of complaints.

Other Environmental Variables Unrelated to IAQ Play a Role in Worker Complaints About Health and Comfort

Advocates of the building systems approach recognize the existence of a number of non-IAQ environmental variables which influence worker perceptions of health and comfort. Hedge et al. have proposed a model which identifies five kinds of variables involved in the determination of sick-building syndrome. (Hedge, 3-955)

These include:

1. Individual factors (age and gender);
2. Organizational factors (type of job);
3. Architectural and engineering factors (type of ventilation, office design, controls/access);
4. Psychosocial factors (stress, satisfaction);
5. Non-IAQ environmental factors (thermal conditions, lighting, noise).

A number of studies in the published literature indicate that lighting, temperature, humidity, job satisfaction, job stress and ergonomics are factors which will influence the kinds of worker perceptions about poor/adequate IAQ. (TDSA, 3-1073) For example, in a SBS study in Denmark, Skov and colleagues examined sick-building syndrome reports among 4,369 office workers. Their research indicated that indoor climate perception was strongly related to the prevalence of SBS symptoms. Lifestyle factors were only weakly associated with the reporting of symptoms." (PM, 3-1074)

A 1991 report by Hawkins and Wang ranked a number of variables related to self-reported symptoms of sick building syndrome.[60] Those variables included: "humidity," "satisfaction with work," "active smoking," "gender," "exposure to PTS," "office light," and "doing professional work." They concluded:

> Building Sickness Score was associated with many factors. Sick building syndrome symptoms are influenced by multiple variables of which the environmental factor of humidity and he psychological factors of work, sex, and occupation are important. (PM, 3-1074)

Based on one of his own studies, Hedge reports that although ventilation has an important effect on indoor air quality, reports from workers in 46 office buildings in the U.K. indicated that complaints were even more strongly influenced by a number of personal and occupational factors such as gender, job stress, job satisfaction and computer use. (3-955)

The American Industrial Hygiene Association (AIHA) reports that "psychosocial and physical stresses are certainly potential causes of some IAQ complaints and should always be considered in any investigation." This opinion is based on the experience of AIHA members. (3-735)

Citing two studies, Eagle Environmental Health reports that "thermal discomfort, unpleasant odors, lack of air movement, insufficient lighting, and excessive noise are also indicated in IAQ investigations. Job-related stress many also manifest itself in IAQ complaints." (3-500)

The National Energy Management Institute (NEMI) reports:

> The NEMI experience has revealed that there are a variety of factors which can interact to cause a worker to display indoor environmental health-related problems. These factors may actually be the primary cause or may exacerbate an IAQ problem condition. Temperature, temperature change, humidity, air velocity, light levels, noise as well as psycho-social factors

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should *always* be considered in presenting and investigating IAQ problems. (3-1183)

The U.S. EPA also recognizes that factors related to SBS are multi-factorial, involving combined environmental and psycho-social stressors. (3-1075; Attachment H) Referencing the World Health Organization (1986), the U.S. EPA notes:

> Buildings at highest risk [of SBS] appear to be new or recently remodeled buildings with tight envelopes, especially those with large ventilation systems that depend on limited fresh air sources. Improper ventilation, thermal conditions, and occupant lack of control over climatic and working conditions are other factors that may increase the likelihood of a building being linked to sick-building syndrome. (3-1075; Attachment E)

A NIOSH psychologist, Dr. Michael Colligan, has offered an explanation for the role of such factors in perceptions about IAQ.[61] (PM, 3-1074) He writes:

> It appears then, that the individual is sensitive to fluctuations in the functioning of the autonomic nervous system. When perceived changes in his subjective state are understandable, e.g., 'I have an allergy,' 'I've been under a lot of pressure to met a deadline,' 'I'm worried about my teenager,' an individual can initiate various coping strategies to deal with the causes. When the origins of the experienced distress are vague or unclear, however, an individual starts searching around for salient cues. If the environment provides a plausible cause in the form of a pungent odor or dense, stuffy air, then an individual can conclude, rightly or wrongly, that the poor quality of the environment is responsible for his physical and psychological discomfort. Notice that this process can occur independently of any specific toxic effects the environment might have on the individual and irrespective of the 'real' cause of the autonomic arousal. All that is required is that individual experience autonomic arousal in response to a subtle or unidentified stressor or combination of stressors. cues provided by the environment in the form of noxious odors, visually detectable particulates or dust, or humid, stuffy air, may suggest to an individual that his discomfort is a toxic response to an airborne pollutant. That environment then becomes a source of threat to the individual, which in turn may generate more autonomic arousal and anxiety.

Dr. Colligan's observations provide an understanding of complaints related to PTS in the workplace. Because it is readily identifiable, PTS is often *initially* blamed for IAQ problems (yet after investigation, reported exposures to PTS are directly associated with complaints in only 2-4 percent of sick buildings). If individuals are "stressed" by their work environment (influenced by such diverse factors as temperature, humidity, air movement, ergonomics, workload, personal problems, etc.), the mere visibility of PTS may provide a cue for a complaint. Recent research by Winneke and colleagues indicates that an individual who is predisposed to annoyance from PTS will be more likely, under actual exposure conditions, to respond with annoyance symptoms.[12] (PM, 3-1074) Researchers from the Illinois Institute of Technology also addressed the issue of nonsmoker perception of annoyance and irritation from PTS exposures. The study, involving over 250 subjects, reported that visual contact with a smoker affects the magnitude of adverse response to PTS among selected nonsmokers. The authors suggest that their conclusion "provides an inexpensive strategy of reducing complaints associated with PTS: eliminate visual contact between smokers and nonsmokers." (IIT, 3-31)

Precise quantitation of psychological variables and perceptions of comfort within the context of complaints about IAQ is extremely difficult. Nevertheless, the influence of those environmental variables upon IAQ complaints should be considered during SBS investigations. The comfort parameters of humidity, temperature and air distribution are related to HVAC performance, and the building systems approach is capable of addressing those factors.

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Ventilation: The Mitigation Procedure for Poor IAQ

Ambient concentrations of substances measured in the non-industrial workplace and reported in the published literature rarely approximate occupational PEL or TLV levels. Moreover, specific substances are rarely identifiable as causes of complaints about poor IAQ. Nevertheless, such complaints are presumed to be "real" (i.e., they may present physiological manifestations) and they may be said to constitute some degree of "material impairment" of the worker.

What remedial and/or preventive measures would reduce non-industrial worker low-level ambient exposures and complaints about IAQ? According to the building systems approach, the appropriate mitigation procedure begins with increased attention to ventilation, and specifically, to adequate supply air, distribution and air filtration. The RFI docket is replete with such recommendations. For example, the New York State Building and Construction Trades Council reports that, based on their experience, "the average office setting exposes workers to contaminants from machines, carpets, paints, glues, and fungi. These contaminants mix with the air the workers breathe on a daily basis and affect a persons well-being. Proper ventilation has been shown to provide a proven antidote to these problems." (3-732)

IAQ investigators from AFSCME Local 12 from the University of Iowa Employees Union report that "we have found that insufficient fresh air flow is most often the cause of a number of symptoms, including coughing, skin and eye irritations, headaches and upper respiratory infections . . . indoor air quality problems can be treated with little effort and expense by improving or upgrading inadequate ventilation systems to increase fresh air flow in the workplace." (3-809)

Investigators from CanTox Inc. agree: "[C]ontrol of the air exchange rate (i.e., ventilation) of a building is probably the most important and practical mediation practice for management of indoor air quality." (3-1180)

The State of New Jersey Health Department's investigation of 221 complaint buildings revealed that over 43 percent of all cases involved inadequate ventilation. In cases where abatement recommendations were made, the recommended strategy consisted of increased maintenance, repair, adjustment or redesign of the HVAC system. Eighty-four percent of the cases where such abatement steps were implemented reported an elimination of complaints." (HBI, 3-1053)

Indoor air quality in schools has recently become an issue of considerable concern. In 1989, Helsing and coworkers reported the results of an IAQ investigation in a school. They reported that "there was an insufficient fresh air supply to some classrooms and a large percentage of students exhibited classic symptoms of sick-building syndrome, i.e., headache, eye burning, fatigue."[63] Similarly, investigations by Hanssen (1987)[63] and Beller (1989)[64] reported that low air exchange rates in combination with installation of new building materials was the main cause of complaints in the schools that they investigated. Helsing et al. concluded: "Correcting the ventilation problems resulted in reduction of symptoms to a level approximately equal to that of students in other schools in the county." (PM, 3-1074)

In a 1991 publication, Thompson et al., described various retrofit projects for HVAC systems in 26 schools across the U.S.[65] The retrofits followed the design specifications set forth in ASHRAE Standard 62-1989 for ventilation. The retrofits were, according to the authors, "very effective" at reducing radon and CO_2 levels in the schools. The authors also reported that "many of the occupants" believed that IAQ had improved. (PM, 1074)

The State of Wisconsin Safety and Building Division reports that, in their experience:

> Almost without fail, . . . complaints are resolved by ventilating the offices or classrooms per state code. This is a provision of outside air (up to 20 cubic feet per minute) per person. . . . These ventilation requirements are supported by the American Society of Heating, Air-Conditioning, and Refrigerating Engineers (ASHRAE). (3-10)

In 1989, Collett and Sterling examined the effect of ventilation retrofits on perceived health and comfort complaints by building occupants. For the buildings in which major retrofits were undertaken, perceptions of indoor air quality improved in seven of nine categories surveyed. (TDSA, 3-1073)

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Downing and Bayer recently reported results from more than 35 building IAQ investigations.[66] They reported that the most "common source of IAQ problems has been the lack of proper operation and maintenance (O&M) of buildings." They further observed that "in more than 80 percent of the investigations to date, changes in building O&M significantly improve the perception of IAQ by the occupants." The researchers recommend, as part of their O&M procedure check list for indoor air quality, "to raise outdoor air ventilation to ASHRAE recommended minimums." (PM, 3-1074)

In 1991, investigators of the U.S. EPA's headquarters in Washington, D.C., reported that they were "unable to establish consistent relationships between major environmental parameters and self-reported health symptoms among the sampled employees." However, based on the number and frequency of complaints among workers in those buildings, the research group recommends that "an attempt to maintain indoor environment in accordance with the ASHRAE guidelines should be made."[67] (PM, 3-1074)

Similarly, Canadian health officials who investigated and compiled the Canadian sick-building database (Health and Welfare Canada) observed that recommendations for improvements in ventilation and thermal comfort had been made in 60 percent of the buildings 1,400 investigated, while control of specific pollutants was recommended in only 20 percent of all cases.[68] (PM, 3-1074)

In 1984, a committee on sick-building syndrome from the WHO's Europe Working Group on Indoor Air Research concluded that an increase in outdoor supply rates, together with improvements in air distribution, had satisfactory results in remediating sick-building syndrome. (Lebowitz, 3-188)

The Ohio Civil Service Employees Association, after reviewing three indoor air quality incidents in Ohio, endorsed the ventilation approach "as a vital component in solving and preventing persistent health and safety problems related to indoor air in the workplace." (3-398)

Steven B. Hayward of the State of California Department of Health Services recommends adoption of a minimum ventilation standard similar to that currently in effect as a Cal/OSHA regulation. The Cal/OSHA standard requires that a minimum supply of outdoor air specified in the State Building Standard Code be provided, and that the HVAC system be operated continuously, inspected regularly, and properly maintained. (3-17A)

A former NIOSH building investigator now associated with a public health department in New York State remarked that "indoor air quality problems are widespread in buildings throughout the state. In almost all cases, the cause of complaints in a given building can be readily identified. In most cases, the problem is the ventilation system for the building. Most often these complaints are due to exposure to multiple substances which are not being adequately exhausted from the building due to inadequate ventilation." (NY Pub. Emp. Fed., 3-444)

Respondents to the RFI also observe that adequate ventilation is the preferred method for controlling exposures to radon, VOC's, PTS, CO, $C)_2$, and bioaerosols. (Eagle EH., 3-500; Burge, 3-61; HBI, 3-1053) Indeed, the U.S. Department of Labor's Occupational Illness Support Group states that PTS and radon . . . "have seldom been the source of employee complaints of poor indoor air quality. With properly designed and properly operated ventilation systems, exposure to radon and passive smoke can be minimized." (3-1017)

Feasibility (Technological and Economic) and Docket Endorsement of Ventilation Rates Prescribed for Various Workplace Settings in ASHRAE Standard 62-1989

Ventilation is the cornerstone of the building systems approach to acceptable indoor air quality. Air changes are required in structures to replace air depleted by human respiration, to remove excess humidity and to dilute and remove airborne substances which are released by indoor sources. Various studies and testimonials submitted in response to the OSHA RFI provide verification for the use of a ventilation approach in the control of indoor air quality.

According to submissions to the OSHA RFI docket, the most widely endorsed guidelines on ventilation have been promulgated by the American Society of

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Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE), a private, standards-writing organization. ASHRAE is a professional organization consisting of architects, mechanical and HVAC engineers, HVAC systems manufacturers, contractors and IAQ mitigation experts. One of the principal functions of ASHRAE is the development of consensus standards relating to heating, ventilation and air-conditioning. ASHRAE develops and promulgates standards which are adopted by building code organizations in the United States. (ASHRAE, 3-440)

In 1989, ASHRAE published a standard entitled "Ventilation for Acceptable Indoor Air Quality."[69] The standard is known as ASHRAE Standard 62-1989 and prescribes the rate at which fresh or outside air must be delivered to occupied spaces, and the various means to condition that air. In 1990, Standard 62-1989 was approved by the American National Standards Institute (ANSI). The Standard has been adopted in twelve states and by two major building code organizations in the United States. It is currently under consideration for adoption by the remaining national building code organizations. (PM, 3-1074)

ASHRAE Standard 62-1989 establishes ventilation rates and procedures for various indoor settings in order to "control dioxide and other contaminants with an adequate margin of safety, and to account for variations among people, varied activity levels, and a moderate amount of smoking."[69]

The ventilation rates recommended by ASHRAE 62-1989 are comparable to rates prescribed for indoor areas in Finland, Sweden, Japan, and Germany. The Standard also accords with the September 1988 draft recommendations by the International Committee on Indoor Air Quality for the providence of Ontario, Canada. That committee recommended a ventilation rate higher than 15 cfm/pp for all "offices, schools and similar non-industrial buildings." (PM, 3-1074)

ASHRAE Standard 62-1989 also recommends limits of exposure to various constituents found in indoor air. The upper limits for exposure are 1/10th of the threshold limit values (TLV's) prescribed by the ACGIH.[69]

The precursor ventilation standard to ASHRAE Standard 62-1989, ASHRAE 62-1981, recommended two levels of ventilation, one for areas in which smoking was permitted, and another substantially lower rate for areas where smoking was prohibited. The prescribed ventilation rate in ASHRAE 62-1981 for offices in which smoking was permitted (20 cubic feet outside air per minute per person; 20 cfm/person) was 4 times greater than the rate recommended for nonsmoking areas (5 cfm/person).

IAQ problems were reported by those who followed the minimum (nonsmoking) ventilation rates specified in ASHRAE 62-1981. Research indicates that the ventilation rate for nonsmoking areas (5 cfm/person) is insufficient to efficiently dilute carbon dioxide and body odor and that occupants under such conditions may complain of "stuffy" air. Other research indicates that a ventilation rate of at least 15 cfm/person, the minimum rate recommended by ASHRAE Standard 62-1989, and three times the rate recommended for nonsmoking areas by ASHRAE 62-1981, would be necessary and sufficient to disperse normally occurring ambient substances (e.g. CO_2, body odors, etc.), as well as tobacco smoke.[70-72] (ASHRAE, 3-440)

In recent testimony before a Congressional Subcommittee, Mr. John Janssen, the Chairman of the ASHRAE Standards Project Committee for 62-1989, stated:

> Prior to the oil embargo of 1973, buildings tended to be over-ventilated and indoor air quality problems were not widely recognized. Ventilation recommendations for office spaces, for example, ranged all the way from 5 to 25 cubic feet per minute per occupant. In 1973, ASHRAE published the first edition of Standard 62, which allowed a minimum of 5 cfm of outdoor air per person for some applications. Most state and city building codes still reference ASHRAE Standard 62-1973, "Standard for Natural and Mechanical Ventilation."
>
> In 1981, the ASHRAE Ventilation Standard was revised to incorporate new technology and new awareness of such issues as tobacco smoke, which was not mentioned in the 1973 version. Research results (some ASHRAE sponsored) showed that the minimum ventilating rate of 5 cfm per occupant permitted under 62-73 would not adequately control

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occupant-emitted odors. At least 15 cfm per occupant was needed to reduce the odor level to a point acceptable to 80 percent of the people entering an occupied space. This amount of ventilation was found sufficient to control tobacco-smoke odor when the smoking rate is about todays average. (PM, 3-1074)

In ASHRAE's submission to the RFI docket, Janssen writes:

> ANSI/ASHRAE Standard 62-1989 is an authoritative guide for achieving acceptable indoor air quality. The Standard defines ventilation rates needed to achieve freedom from odor, irritation and create a comfortable indoor environment. As the only nationwide consensus-based technical standard on ventilation and acceptable indoor air quality, ASHRAE recommends Standard 62-1989 as the standard of choice for adoption by reference for state and local building codes and regulations. (3-440)

A number of respondents to the RFI endorse the ventilation procedure specified in ASHRAE Standard 62-1989 and recommend its adoption as the basis to possible OSHA recommendations on IAQ. (Law Associates 3-1200; ENV Services, Inc., 3-1089; Organization Resources Counselors, Inc., 3-1084; the National Environmental Development Association's Total Indoor Environmental Quality Coalition (NEDA/TIEQ), 3-1054; Healthy Buildings International (HBI), 3-1053; Systems Applications International (SAI), 3-1052; U.S. Navy, 3-982; Stellmack Air Conditioning and Refrigeration, 3-978; Oklahoma Dept. of Labor, 3-945; Pennsylvania AFL-CIO, 3-908B; Duke Power Company, 3-860; American Association of Occupational Health Nurses (AAOHN), 3-803; American Federation of Government Employees, 3-529; ASHRAE, 3-440.)

Other respondents, including governmental and private IAQ investigators and mitigation experts, industrial hygienists and engineers, recommend use of the Standard for achieving acceptable indoor air quality. (Meckler Engineers Group, 3-1081; Theodor D. Sterling & Associates (TDSA), 3-1073; Occupational Illness Support Group Local 12, 3-1017; R.J. Reynolds Tobacco Company (RJR), 3-1087; U.S. Navy, 3-982; Business Council on Indoor Air (BCIA), 3-933; Gershon Meckler Associates, 3-879; the Center for Environmental Assessment, Inc., 3-687; Sheet Metal and Air Conditioning Contractor's National Association, Inc. (SMACNA), 3-856; International Brotherhood of Teamsters, 3-858; Consolidated Edison Company of New York, 3-828; Caterpillar, Inc., 3-805; Philip Morris Companies, 3-1074; United Technologies, 3-651; Dow Chemical Company, 3-502; Thomas E. Glavinich, D.E., P.E., 3-498; Ford Motor Company, 3-447; Systems Applications International (SAI), 3-1052.)

One of the largest private IAQ diagnostic and mitigation firms in the U.S., Healthy Buildings International, Inc., writes that "ASHRAE Standard 62-1989, 'Ventilation for Acceptable Air Quality,' is perhaps the single most useful document we have in our efforts to communicate the proper practices for ensuring good indoor air quality in commercial buildings. We support its use, continued development and incorporation into future building codes, standards and IAQ legislation." (3-1053)

The submission by Meckler Engineers Group states:

> ASHRAE Standard 62-1989 is the only recognized authority that specifies the desired performance of building ventilation systems. . . . If OSHA decides that it is appropriate to regulate workplace IAQ at the national level, adoption of ASHRAE Standard 62-1989 would be the best strategy. (3-1081)

The EPA's submission to OSHA includes its handbook for remediation of indoor air quality problems. EPA's recommendations include: "Compare design air quantities to building codes for the current occupancy or ventilation guidelines (e.g., ASHRAE 62-1989), and compare ventilation rates to ASHRAE 62-1989." The handbook also recommends that it would be "informative to see how your ventilation rate compares to ASHRAE 62-1989, because that guideline was developed with the goal of preventing IAQ problems." (EPA, 3-1075 D)

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Ventilation Effectiveness: The Ventilation Rates Specified in ASHRAE 62-1989 Are Effective in the Mitigation of Poor IAQ and the Maintenance of Acceptable IAQ, According to Scientific Data and the Professional Experience of IAQ Experts

ASHRAE Standard 62-1989 prescribes the rate at which fresh or outside air must be delivered to occupied spaces and the various means to condition that air. The Standard recommends a ventilation rate of 20 cubic feet of outside air per minute per person for most commercial and non-industrial workplace facilities, with 15 cfm as the minimum ventilation rate. However, the key question is whether or not the ventilation rates specified by ASHRAE 62-1989 are sufficient to *mitigate* poor indoor air quality and to *maintain* acceptable indoor air quality. A number of submissions to the OSHA RFI provide data which support the effectiveness of ASHRAE 62-1989. For example, the submission by the National Environmental Development Associations' Total Indoor Environment Quality Coalition states that "while data do not exist to determine the optimal ventilation rate, the ASHRAE Standard [rate] of 20 cubic feet per minute per person appears to maintain adequate air quality in environments where the HVAC systems are designed to deliver that ventilation, and where those systems are properly maintained." (3-1054)

The Food and Allied Services Trade Union states that ensuring an adequate fresh air supply "has been shown to be the single most effective method of correcting and preventing problems and complaints related to poor indoor air quality. . . . fresh outdoor air should be adequately distributed to all office areas during the entire time they are occupied, at a minimum rate of 20 cfm per person." (3-434)

A number of recently published studies on ventilation effectiveness also support the ventilation rates of ASHRAE 62-1989. In 1991, Menzies et al. concluded, after examining the effect of various levels of outdoor ventilation on sick-building syndrome symptoms, that "increasing the amount of outdoor air from 20 to 50 cfm per person did not result in a reduction of symptoms considered typical of SBS among office workers."[73] The authors concluded that "this study supports the continued use of 20 cfm pp as the minimum standard for the supply of outdoor air to indoor non-industrial space." Similarly, Nagda et al. reported on a study conducted in a 20-story government office building. Although they reported limited differences in measured and perceived indoor air quality comfort complaints, they concluded that "occupants consistently reported fewer health symptoms in the presence of higher ventilation."[74] (PM, 3-1074)

IAQ investigators Downing and Bayer recommend, as part of their operation and maintenance procedure checklist for achieving acceptable indoor air quality, raising "outdoor air ventilation to ASHRAE-recommended minimums."[66] This recommendation has led to improved perception of IAQ by occupants in more than 80 percent of the investigations completed to date by the researchers. (PM, 3-1074)

In a sick-building case investigation featured in *Indoor Air Quality Update* (October 1991), investigators reported "uncomfortable environmental conditions in all locations due to inadequate air flow rates, which range from 30 percent to 70 percent below the ASHRAE design standard of 20 cfm/person in office environments."[75] The investigators recommended an increase of fresh air ventilation in accordance with the ASHRAE Standard for ventilation in order to "improve air circulation and comfort levels." (PM, 3-1074)

Hicks (1984) reported reduced symptom prevalence of eye irritation, sinus congestion and headache when outside air ventilation rates were increased in two buildings in California. In the first building, an increase in the ventilation rate from 5-7 cfm/person to 25-32 cfm/person led to a reduction in symptom prevalence from 60-73 percent to 25-32 percent. Similar results were reported in the second building, where an increase in ventilation from 4 cfm/person to 22 cfm/person lead to a reduction in symptoms (from 48-57 percent to 23-34 percent). (Reported in TDSA, 3-1073) These data support the claim that compliance with ventilation rates specified in ASHRAE Standard 62-1989 (i.e. 20 cfm/person) has a positive impact on occupant comfort perceptions.

Investigators from HBI, Inc. recently reported on an indoor air quality investigation in a school in which they recommended, in order to "prevent the build-up of all indoor airborne pollutants within the building . . . that ASHRAE's suggested ventilation rate of 15 cfm/person be obtained throughout the building during times of occupancy."[76] Similarly, Turner and co-

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workers investigated 29 different schools in which they reported that the "amount of ventilation being provided was, in general, found to fall short of the current ASHRAE Standard 62-1989 guidelines." The researchers recommended that each school operate under the ventilation rates prescribed by ASHRAE Standard 62-1989.[77] (PM, 3-1074)

The effectiveness of ASHRAE Standard 62-1989 for dilution of PTS constituents has also been evaluated by scientists. In 1990, researchers presented results of their work comparing the effects of increased ventilation recommended by ASHRAE 62-1989 in areas where smoking is permitted and in areas where it is prohibited.[78] Through the aid of computer models, the researchers demonstrated that air quality in the areas where smoking is permitted does not differ significantly from the quality of air in nonsmoking areas, where both areas are supplied with outdoor air at levels recommended by ASHRAE 62-1989. (Holcomb, 3-1065)

In their review of PTS-related air quality monitoring in different workplaces under various smoking conditions, researchers from TDSA Ltd. conclude "in office areas in which (a) smoking is allowed, and (b) outside air ventilation rates meet or exceed the ASHRAE ventilation standard, nicotine concentrations have typically been less than 5 ug/m³ and respirable suspended particle levels have ranged between 20 ug/m³ and 60 ug/m³.[16,22,42] (TDSA, 3-1073)

In their submission to the OSHA docket, scientists from HBI, Inc. summarized the results of a paper entitled "The Measurement of Environmental Tobacco Smoke in 585 Office Environments."[41] (HBI, 3-1053) The authors write:

> Computer analysis shows that when 'blindfolded' for presence or absence of smokers, in most cases realistic smoking levels do not significantly influence the aspects of air quality that were measured, and spill over from smoking areas into nonsmoking areas appears to minimal. This work further reinforces the position the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has taken on ETS in office buildings in ASHRAE Standard 62-1989 (1989), that acceptable air quality can be maintained in properly ventilated offices with a moderate amount of smoking, even without smoker segregation.

Professor Alan Hedge offers the following observation on the basis of his extensive experience in monitoring PTS constituents during investigations of sick-building syndrome: "Our data show that modern ventilation systems are capable of diluting the small pollutant loads from smoking at the levels which we observe, without necessarily exposing nonsmokers to significant elevated levels of indoor air pollutants." (3-955)

Company scientists from R.J. Reynolds reported on a recently completed study of four office buildings. (RJR, 3-1087) Two of the buildings investigated had a policy of unrestricted smoking; in the other two buildings, smoking was restricted to separately exhausted lounges. Regardless of smoking policy, RJR reports all ventilation and indoor air quality indicators were "well within applicable standards." The authors write:

> In summary this study demonstrates conclusively (a) that with an HVAC system that is adequately designed, operated in accordance with current ASHRAE standards and properly maintained, all indicators for PTS are at extremely low, *de minimis* levels, even in the presence of substantial smoking activity, and (b) that such smoking activity has a negligible effect on contaminant levels in buildings where smoking is unrestricted. (3-1087)

RJR concludes:

> RJR believes, based on its own detailed research and the consistent results of other workplace assessments, that a properly designed and maintained HVAC system that is operated in accordance with the ventilation rate procedures of the ASHRAE Standard 62-1989, will be effective in assuring that exposures to PTS will be *de minimis*.

Based on their own case studies, the National Energy Management Institute (NEMI) acknowledges that exposure "to the odor caused by excessively high concentrations of PTS can be annoying to nonsmokers." NEMI suggests that "several avenues exist to address this problem. First and foremost is to apply the ASHRAE 62-1989

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ventilation standard . . . workplaces operating in accordance with ASHRAE 62-1989 will not have PTS annoyance problems because the ventilation system will effectively remove all smoke." (3-1183)

In their comprehensive review of indoor air quality in non-industrial occupational environments, Morey and Singh write that "ASHRAE Standard 62-1989 is probably the most important document in the IAQ literature."? (Morey, 3-505) They note:

> It reflects a consensus reached since 1983 by knowledgeable individuals from engineering, industrial and academic groups. Janssen points out that the ventilation rates recommended in Standard 62-1989 for the most part are similar to 'recommended' rates in Standard 62-1973 and to the rates recommended for smoking environments in Standard 62-1981.
>
> A key feature of Standard 62-1989 and its ventilation rate procedure is the increase in the minimum outdoor ventilation rate from 5 to 15 cfm per person. Outdoor air requirements recommended by the ventilation rate procedure make no distinction between 'smoking-allowed' and 'smoking-prohibited' areas. A minimum of 15 cfm of outdoor air per person as specified in the ventilation rate procedure is recommended because new research indicated that this is the minimum amount of outdoor air needed to dilute body and tobacco smoke odors to acceptable levels. The outdoor air requirements specified in the ventilation rate procedure must be delivered to the occupied zone. Design assumptions with regard to ventilation rates and air distribution to the occupied zone are required by Standard 62-1989.
>
> Standard 62-1989 also requires that the design documentation for a HVAC system state clearly which assumptions are used in design. This allows others to estimate the limits of the HVAC system in removing air contaminants prior to commissioning and prior to the introduction of new contaminant sources into the occupied space.
>
> A key provision in Standard 62-1989 now requires that when the supply of air to the occupied zone is reduced (for example, in VAV systems), provision be made to maintain minimum flow rates of outdoor air throughout the occupied zone.

The Building Systems Approach is Cost-Effective; Costs Due to Increased HVAC Use Are Likely to be Minimal and Offset by Improvements in Worker Comfort and Well-Being

Critics of the building systems approach to acceptable indoor air quality suggest that initial construction costs, operating costs and maintenance costs associated with increased ventilation would be burdensome to the building owner or manager. However, this claim does not appear to be supported by any specific data submitted in response to the OSHA RFI. On the contrary, published data indicate that initial and operating costs associated with increased ventilation rates specified in ASHRAE 62-1989 would be minimal, and that maintenance costs would be virtually unaffected by an increase in ventilation. Indeed, the data suggest that any increased costs associated with the building systems approach would be more than offset by a reduction in employee absenteeism and complaints, and a potential improvement in worker productivity. Many respondents to the OSHA RFI believe that the building systems approach may be the most cost-effective approach to the maintenance of acceptable indoor air quality. (For a review of the RFI Docket on the costs of upgrading ventilation systems, see Appendix V.)

Data submitted to the OSHA RFI specifically address the anticipated and real costs associated with the adoption of the ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality." The Standard has already been adopted in 12 states and by 2 major building code organizations in the United States. It is currently under consideration for adoption by the remaining national building code organizations. If adopted by building code organizations, municipal and local governments in the U.S. will include the Standard as part of their local governing building code. ASHRAE 62-1989 will then serve as the design standard for ventilation for all *new* and *retrofitted* buildings.

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An earlier version of the ventilation standard, ASHRAE 62-1973, specified a recommended ventilation rate of 15 cfm/person. The 1973 version of the Standard was incorporated into building codes and was in effect throughout the 1980s. (ASHRAE Standard 62-1981, which specified a minimum ventilation rate of 5 cfm/person, did not receive approval by ANSI and was not adopted by building code organizations.) There are few differences in design specifications between the recommended ventilation rates in Standard 62-1973 and the minimum ventilation rates specified in ASHRAE Standard 62-1989. Therefore, capital (initial or first) costs are not likely to be appreciably higher for the 1989 version of the Standard than those required by ASHRAE 62-1973.

It is recognized by contributors to the OSHA RFI that any increased costs associated with the adoption of ASHRAE 62-1989 will vary according to specific workplace configurations. Both the 1973 and 1981 versions of Standard 62 permitted a minimum ventilation rate of 5 cfm/person, compared with the minimum rate of 15-20 cfm/person specified by ASHRAE 62-1989. Energy costs associated with the operation of ventilation systems in compliance with the minimum recommendations in ASHRAE 62-1989 therefore can be expected to increase annual energy budgets for some buildings, depending upon the location of the building.[80-84] However, maintenance costs for HVAC systems should not vary appreciably from those in compliance with either the 1973 or 1981 versions of the ASHRAE Standard.

The impact of increased (outside air) ventilation rates upon initial costs and annual operating costs has been assessed by researchers from Lawrence Berkley Laboratory (LBL).[80-81] Using a series of computer simulations, the authors estimated changes in initial and operating costs associated with increasing minimum outside air supplies from 5 cfm/person to 20 cfm/person. The prototype for the simulations was a standard 100,000 ft² building in 13 different locations throughout the United States and Canada. Estimated capital costs for HVAC equipment were small, amounting to less than 5 percent of total building costs or, at most, 35 cents/ft². Operating costs for heating were estimated to increase by a maximum of 8 percent annually; costs for cooling increased to a maximum of 14 percent. Average annual energy operating costs were estimated to increase by about 3-5 percent overall. (TDSA, 3-1073)

In 1990, the LBL authors extended the computer simulations to apply to small and medium size office buildings.[82] Annual energy costs were estimated to increase about 5 percent for small office buildings and 3 percent for medium sized offices. (TDSA, 3-1073)

Recent testimony from The Sheet Metal and Air-Conditioning Contractors National Association (SMACNA) before Congress describes another simulated study which estimates that an increase from 5 to 20 percent outside air would cost an additional $1,800 in annual energy expenditures for a 100,000 square foot office building.[83] This is equivalent to an increased operating cost of about $0.02 per square foot. (SMACNA, 3-1073)

The submission from the BCIA reports:

> The Bonneville Power Authority and the Department of Energy have both estimated that the energy penalty for bringing ventilation rates into compliance with the ASHRAE Standard would be in the range of 4 to 5 percent regardless of the buildings type or location . . . an analysis by Flatheim concluded that increased energy consumption resulting from upgrading IAQ may total as much as 8 percent, but is more than compensated for by a 1 percent improvement in productivity. (3-933)

The BCIA submission continues:

> The costs of complying with the ASHRAE Standard will depend, in large part, on the building size and location. For a 36,000 square feet building in southern California the costs associated with increasing the ventilation from 5-20 cfm/person was $0.25 to $0.30 per square foot per year. This cost was associated with cooling and did not involve additional ducting-zoning costs or any control costs.

The submission from TDSA Ltd. reports on an estimate of the incremental capital costs of incorporating the ASHRAE Standard into a 200,000 ft² office building. The researchers note that the mechanical engineers' initial estimate of the increased capital costs was less than $7,000, or approximately $0.04/ft², for a building project budgeted at $20,000,000. (TDSA, 3-1073)

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Comments from Mr. Joseph Ventresca report on a model energy consumption simulation for a 100,000 ft² office building located in Columbus, Ohio.[84] Cost increases associated with an increase in outside air from 5 to 20 cfm/person were: "Heating energy increases of 0 percent to 8 percent; cooling energy increases of 1 percent to 14 percent, electric demand increases of 0.5 percent to 8 percent; insignificant fan energy increases; and total energy cost increases of less than 5 percent." (Ventresca, 3-941)

Additional submissions to the OSHA RFI docket suggest that increases in ventilation rates to meet ASHRAE Standard 62-1989 will not necessarily increase annual energy budgets. (EPA, 3-1075D; G. Meckler, 3-879; Ventresca, 3-941) TDSA Ltd. concludes that any "increased costs are minimal, both in real terms and in relation to the potential savings in reduced absenteeism and improved productivity associated with increased occupant satisfaction with indoor environmental condition." (3-1073)

Other submissions to the OSHA RFI docket agree with TDSA Ltd.'s analysis. For example, in SMACNA's building energy cost simulation study, additional outside air ventilation was estimated to increase energy costs by about $1,800 on an annual basis for a 100,000 square foot building.[85] According to SMACNA, the same study "compared the cost of absent or sick workers affected by unhealthy ventilation and concluded that increased ventilation costs 1/135 of the costs of absent and sick employees." (SMACNA, 3-856)

In a 1991 publication, Mr. Peter Binnie describes a hypothetical situation where energy costs for maintaining acceptable IAQ are considered in terms of employee absentee rates.[85] He writes:

> Consider the following situation. In a typical building of 100,000 square feet, the move from 20 cubic feet per minute (10 litres per second) of fresh air per person down to, say, 5 cubic feet per minute (2.5 litres per second) per person may on average result in cost savings of perhaps $20,000 per annum. This could represent a 40% savings in the energy costs associated with ventilation, or 10-15% of the building's overall energy budget. Everyone in upper management would be pleased, and one can be certain that future years' budgets would be reduced to reflect the actual costs of this first year. Thus, the building is now doomed to function with no more than 5 cubic feet per minute (2.5 litres per second) per person. As HBI, ASHRAE and many others have found, this action results in unacceptable indoor pollution and increased absentee rates.
>
> In the United States and Europe, offices are commonly staffed with a generous average of 150 square feet of space per employee. Thus, in the hypothetical building of 100,000 square feet, there would be 67 staff. If they are paid the minimum wage of $15,000 per annum, the payroll bill would reach $10 million per annum. This means that every 1% of absenteeism would cost $100,000 per annum. Surely a decision to save $20,000 per year on energy that results in reducing worker productivity and increasing absentee rates involving hundreds of thousands of dollars in costs is poor business judgment. (Armitage, 3-934)

Similarly, a 1990 report issued by the United States Air Force estimates the following:[86]

> The cost of personnel in the Air Force averages about $250.00 per square foot per year. The maintenance and energy costs for all operations in a building rarely exceed $7.00 per square foot per year. Of the $7.00, no more than $2.00 are energy costs. If the unlikely proved true and we saved half of all energy costs by running closed or minimum fresh air cycles, that would be $1.00/sq ft/yr. This is the equivalent of seven hours per square foot of personnel time. This is less than two minutes per day per year. If only two minutes per day productive time is lost, then all energy savings are wiped out. Respiratory disease is at least 1.5 to 3 times more likely in a tight environment. Common respiratory infection episodes last eight to ten days with one to two days of absence being usual. The average number of respiratory infections involving colds and flu is one per person per year based on National Center for Health

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Statistics data. Tight buildings are likely to raise that number to between 1.5 and 3.0 episodes per person per year. Using the lower figure of one day of loss per episode, we have raised the lost days from one to between 1.5 and 3 per person per year with an average of 2.25 days. This is an average increase of 1.25 days. By this measure alone we have lost 10 hours, three more than is required to put us in the deficit column. Three of the days of infection are likely to suffer from reduced productivity by at least 20% for a total of 60% of a day. Cost is now 1.85 excess days lost; 1.85/220 = 0.84% x $250/sq ft/yr = $2.10/sq ft/yr. This cost already exceeds the savings possible by running the air handler with inadequate fresh air by 2.1 times. This analysis does not begin to address the losses due to aggravation of pre-existing problems such as asthma and allergies, the cost of other diseases known to result from improper maintenance and operation of air handlers, the loss in productivity due to irritant effects of poorly controlled 'comfort' parameters or the losses due to the social atmosphere surrounding the problems generated. The actual savings from running closed cycle are even less than the generous $1.00 we allowed. It is usually necessary to increase total outside added air from roughly 10% of total flow to obtain adequate fresh air and control CO_2 to appropriate levels. If all of the $2.00 were going to climate control, this represents only 20 cents rather than a dollar in savings. Since this is so, the actual relative loss from increase in infections is $2.10/0.20 = 10.5 times the possible energy savings if all energy is used for heating. This is a poor bargain. (PM, 3-1074; Poirast, 3-34)

Several researchers have argued that the costs of increased worker absenteeism attributable to poor indoor air quality would greatly exceed any energy expenditures due to increased ventilation. Using a 100,000 square feet office building as an example, researchers have estimated that increased energy costs for a year would be equivalent to costs associated with _ day of absenteeism over the buildings entire workforce.[85] (HBI, 3-1053; Armitage, 3-934) Another investigator suggested that a one percent absenteeism rate would be equivalent to an expenditure of over $100,000 annually, compared to an increased annual cost for ventilation of $20,000.[87]

Thus any anticipated cost increases due to incorporation of ASHRAE 62-1989 will be offset by improvements in productivity and projected reductions in absenteeism. One reviewer notes:[87]

> The enlightened owner or energy manager must develop a new perspective of energy costs and comparable air quality costs. It has been suggested that such a comparison could compare the annual cost of energy on a square foot basis to the annual cost of human capital on a square foot basis. The latter 'productivity factor' would use annual wage and salary and health cost line items and divide by the occupied office space. Using a typical comparison, energy could be assumed at around $3.00 sq/ft/yr, but human capital will typically be as much as $300 sq/ft/yr. From this perspective, even a dramatic change of 25-50 percent of energy costs equates to only a few minutes of human capital time . . . or productivity. Productivity therefore becomes the dramatic dominant economic factor. (3-1074)

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Source Control: The Alternative Mitigation Strategy for Poor IAQ

Scientific data support the effectiveness of the ventilation rates prescribed by ASHRAE Standard 62-1989 for improvement and maintenance of indoor air quality. The ventilation rates were specifically designed to "control carbon dioxide and other contaminants with an adequate margin of safety, to account for variations among people, varied activity levels, and a moderate amount of smoking."[69] The available published scientific literature submitted to the OSHA RFI docket supports this position.

Several submissions to the OSHA RFI docket reject the building systems approach and recommend that more attention be given to controlling sources of indoor air pollution. Advocates of source control argue that (1) the costs associated with increased ventilation will be prohibitive; (2) a building systems approach would generate unnecessary regulations and government involvement in business, and (3) particular chemical agents can be identified at exposure levels that constitute risks to workers, and the agents' removal will not incur significant cost.

Source Control: Fails to Address Total IAQ and is Not Supported by Data on Source Strengths, Exposures or Health Effects

The building systems approach and the source control approach to IAQ are not necessarily mutually exclusive, but a large part of the source control strategy would appear to be the result of a misunderstanding of the IAQ issue. This fundamental misunderstanding generates mitigation strategies which fall short of satisfying objectives for total acceptable indoor air quality. For example, a source control strategy cannot address the fundamental issues of the building systems approach, namely, the dilution and removal of by-products of human metabolism and non-industrial work-related activities. The ventilation rates prescribed by ASHRAE 62-1989 are intended to effectively dilute and remove water vapor, carbon dioxide, odors and particles associated with human metabolism, as well as the by-products of work-related processes and activities typically found in an office, school or retail setting. Such processes or activities range from simple movement (and the raising of dust particles from carpets) to food preparation, cleaning, copying and smoking.

Sole reliance upon source control for achieving acceptable indoor air quality ignores another fundamental principle of the building systems approach, i.e., that a specific airborne source often cannot be identified and associated with complaints about IAQ. Even advocates of source control recognize this failure. For example, one proponent writes that while the importance of a source is "a function of the health effects of its emissions . . . not enough is known about these effects." Moreover, the author realizes that "we are unlikely to have a great deal more information about health effects in the foreseeable future." Indeed, it is also recognized that "even the strength of source emissions is not well understood for most products."

The advocate of source control fails to acknowledge that the presence of *some* constituents in indoor air is unavoidable, and that inadequate ventilation has been identified as one of the major causes of complaints about IAQ. Source control addresses neither of those issues.

Other potential problems associated with a source control approach to IAQ could be insurmountable. For example, of the thousands of possible constituents in indoor air, which are to be "controlled at the source?" Who will decide — a building manager, operator, or an indoor air quality mitigation expert? Will indoor air quality monitoring be required for all non-industrial workplaces? (This would constitute a cost-prohibitive recommendation; see Appendix VI concerning the costs of monitoring and laboratory analysis for indoor air pollutants.) At what level of exposure would a program for removal of a given source be activated? The latter question presupposes the development of a program of PELs or TLVs for exposures to potential

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substances in the non-industrial workplace, which would be presumably different than those specified by OSHA for industrial workers. Yet, by the admission of the advocates of source control, such a program could not be based on actual data because source emissions are "not well understood for most products." (Levin, 1991)

A Source Control Example: The Smoking Ban

A smoking ban is the most common example of the source control strategy, perhaps because it is perceived as a quick, simple and inexpensive "solution" to complaints about IAQ. Advocates of the smoking ban argue that only a ban will eliminate the purported "risk" associated with exposure to ETS in the workplace. (ASH, 3-991 and 3-1030; Repace and Lowrey, 3-1061; EPA, 3-1075)

The 1986 Surgeon General's Report suggested that simple separation of smokers and nonsmokers would not eliminate exposure to ETS, and this position is relied upon by advocates of the smoking ban. However, the Surgeon General's opinion was not based upon actual scientific data regarding the efficacy of simple separation of smokers and nonsmokers. Moreover, the implementation of a smoking ban as a approach to the mitigation of IAQ problems ultimately fails to address critical IAQ issues. For example, the smoking ban advocate completely ignores compelling data from the various sick-building syndrome databases which indicate that rarely, if ever, are complaints about indoor air quality related to smoking. The smoking ban proponent also ignores additional data that suggest that typical nonsmoker exposure in the workplace is minimal, that epidemiologic studies on reported exposures to PTS in the workplace and chronic disease do not support the claim that PTS poses an increased risk for nonsmokers, and that the ventilation rates prescribed by ASHRAE 62-1989 will effectively dilute and remove PTS constituents from the workplace. A smoking ban itself will do nothing to improve fresh air ventilation, and nothing to address exposure to other substances in the indoor air.

A number of submissions to the OSHA RFI docket confirm the foregoing criticisms of the smoking ban. For example, according to the American Federation of Government Employees:

> AFGE's experience indicates while PTS may be a problem in a small number of situations, complaints of smoke in the air are generally a symptom of a poorly designed and maintained ventilation system. Nevertheless, some employers seek to ban or restrict smoking to eliminate the visible symptoms of ventilation, and thus divert attention from a host of unseen toxic substances commonly found in the work environment. (3-529)

Similarly, another union observes:

> Poor air quality is often blamed on smoke. While second hand smoke may contribute to a problem, it is poor ventilation that is a real cause of the problem. Workers are divided emotionally, smokers vs. nonsmokers, and a solution to poor indoor air quality is negotiated on the smoking issue alone. Then, improving the ventilation system is postponed until the smoking policy is given ample time to fail. (SEIU 3-630)

Building investigators from HBI have noted:

> Smoke accumulation within offices may be only the tip of the iceberg. If smoke is trapped by bad ventilation so are all other indoor pollutants. Many of these invisible chemicals, dust, fibers, bacteria, and fungi can have acute or long term health effects on the building occupants . . . [R]eacting solely to the visible evidence of poor ventilation omits invisible pollutants and certainly does not address the fundamental problem of inadequate ventilation. (HBI, 3-1053)

The HBI submission further suggests that "the need to implement a smoking policy in an office building often results from poor HVAC operation and maintenance practices that cause a plethora of IAQ problems, the only visible symptom of which is an accumulation of tobacco smoke." (3-1053)

The RFI submission from the Ford Motor Company undermines the fundamental assumption of the smoking ban advocates' position, i.e.:

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PTS/ETS and IAQ issues are not associated with significant air contaminant concentrations. In resolving this issue, government and management come head on into a basic philosophical dilemma of should there be one set of air contaminant limits for the office and one for the shop floor. If one subscribes to the theory that PTS/ETS in the concentrations normally found in offices is carcinogenic, then one would also have to conclude that most workers in factories and garages are exposed to harmful levels of carcinogens. Even conservative epidemiological studies suggest that this type of epidemic does not exist in the American workplace. (3-447, 3-433)

Thus, a smoking ban is a one-dimensional approach to indoor air quality — one which does not improve fresh air ventilation and one which will not ensure acceptable indoor air quality. This clearly has been recognized by ASHRAE in its recent revision of its Standard for Ventilation, Standard 62-1989. ASHRAE rejected ventilation rates which were predicated solely on the presence or absence of smoking. (Standard 62-1981)

Even the staunchest proponents of source control appear to concede that smoking bans will not improve ventilation or address other substances in indoor air. An EPA health official was quoted as saying recently "looking for single chemical contaminants isn't the answer" to the problem of indoor air quality.[84] In that same article, the director of the EPA's Indoor Air Division, Robert Axelrad, stressed that "people should not be allowed to believe that addressing smoking will solve (all indoor air quality problems)" in spite of his belief that tobacco smoke is "the most prevalent pollutant." Said Axelrad: "There are hundreds of other contaminants that need to be addressed." (PM, 1074)

A smoking ban, therefore, represents a "solution" which may not appreciably reduce nonsmoker exposure to substances in the indoor air, because it fails to address the issue of *total* indoor air quality.

Other Workplace Smoking Policy Options

While a smoking ban represents an extreme and apparently misguided approach to total indoor air quality, some individuals report annoyance and even irritation by the sight or smell of tobacco smoke. Such complaints about exposure to PTS typically have been addressed by employers with one or more of the following:

1. Increase outdoor air ventilation to levels specified in local building codes, or more recently, to levels specified in ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality;"
2. relocation of a work station;
3. grouping of smokers and nonsmokers;
4. the use of partitions in "open" office settings; and
5. the use of desk top air cleaners or "smokeless ashtrays" for smokers.

Such measures have been effective historically in addressing complaints about PTS and require few additional costs from an employer. These remedies are based on the concept of accommodation for both smokers and nonsmokers. In addition, and more important, scientific data submitted to the OSHA RFI docket indicate that these common solutions, including adequate ventilation and the simple separation of smokers and nonsmokers, are effective in providing acceptable indoor air quality and for minimizing nonsmoker exposure to ETS.

Simple Separation of Smokers and Nonsmokers, Even Under Conditions of Recirculation, Effectively Minimizes PTS Exposure of Nonsmokers: Data Do Not Support a Significant Reduction in PTS Exposures (or "Risk" Imputed to PTS Exposures) Beyond Adequate Ventilation and/or Simple Separation of Smokers and Nonsmokers

A number of studies in the published literature have evaluated exposure to PTS constituents under various kinds of smoking policies. Typical constituents measured include: respirable suspended particulates (RSP), UV-PM, nicotine, carbon monoxide and carbon dioxide. The measurements are undertaken in both smoking and nonsmoking areas, usually under general recirculation conditions.

The results reported in the published literature indicate that simple separation of smokers and nonsmokers, under general recirculating ventilation

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conditions, can reduce nonsmoker exposure by as much as 80-98%.

One recent study reported that the use of designated smoking areas reduced exposure to PTS by as much as 95%.89 Another study of a smoking-restricted office building reported that ambient nicotine in nonsmoking areas was virtually undetectable, suggesting that PTS had a negligible impact on the nonsmoking areas of the building.[90] (PM, 3-1074)

Canadian researchers, in a series of reports, presented results on levels of PTS constituents in offices where smoking was regulated and unregulated. They reported no significant differences in average PTS constituent levels between nonsmoking offices that received recirculated air from designated smoking areas and nonsmoking offices that did not receive recirculated air.[16,22,43] Nicotine concentrations reported for nonsmoking areas were marginally about limits of detection; there were no measurable differences in RSP or CO levels in nonsmoking areas that did or did not receive recirculated air from smoking areas. (TDSA, 3-1073) They concluded:

> The results indicate that the provision of a designated, but not separately ventilated smoking area can effectively eliminate or drastically reduce most components of environmental tobacco smoke from nonsmoking offices.

Hedge et al., in 1991 reported results of PTS constituent measurements under five different kinds of smoking policies.[91] Their results are reported below:

> A study of the effects of smoking policy on indoor air quality and sick building syndrome symptoms among 3,155 workers in 18 private sector air-conditioned office buildings is described. Five smoking policies were investigated: smoking prohibited, smoking restricted to rooms with local filtration, smoking restricted to rooms with no local air treatment, smoking restricted to rooms with separate ventilation, and smoking restricted to the open-plan cubicle workstations and enclosed offices. Levels of carbon monoxide, carbon dioxide, respirable particulates, formaldehyde, ultraviolet particulate mass, nicotine, air temperature, and relative humidity were measured at eight sample sites in each building. Approximately 30 workers at each of the eight sample sites completed an extensive questionnaire on environmental conditions, sick building syndrome symptoms, job satisfaction, job stress, smoking history, and personal details. Indoor air quality measures met the current ASHRAE 62-1989 standard. Comparison of all open-office sites between policies showed no significant differences in levels of carbon monoxide, carbon dioxide, formaldehyde or respirable particulates. Levels of ultraviolet particulate mass and relative humidity were significantly lower in buildings where smoking is prohibited, and air temperature was significantly higher in these buildings, although on average this was <1_C. Among all buildings, air temperature was the only physical measure that was significantly correlated with SBS symptoms. Smoking policy had no significant effect on sick building syndrome symptoms.

And:

> Smoking policy had a relatively small effect on IAQ for the pollutants measured. For most of these pollutants, there were no significant differences in concentration among offices in SP buildings, nonsmoking office areas in RF, RSV, and RNT buildings, and office areas in RWS buildings. There was a significant effect of smoking policy on UVPM and formaldehyde in these office areas, which was due primarily to higher levels in the RF and RSV policies. However, all concentrations of UVPM and formaldehyde were low. UVPM was not significantly correlated with gravimetric RSP, even though the UVPM samples were derived from these RSP samples. UVPM did correlate significantly with metered RSP ($r = 0.69$, $p = 0.0001$) and with nicotine ($r = 0.45$, $p = 0.002$), which suggests that UVPM is measuring particulates from ETS. (Hedge, 3-955)

Lee and co-workers (1985) evaluated the effects of a smoking policy on airborne PTS constituent levels.[92] They reported:

> A new smoking policy was implemented on a trial basis on one floor of a large modern Canadian office building. Smoking was

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limited to a single enclosed room which shared the same recirculating-type ventilation system with the rest of the floor. Environmental monitoring was conducted on the test floor and a control floor during three consecutive working days both before and after policy implementation. Hourly levels of respirable suspended particulate (RSP), carbon monoxide (CO) and carbon dioxide (CO_2) were monitored on the floors and in the designated smoking area throughout the workday. Temperature and relative humidity were monitored at specific sites on each floor and the quantity of outdoor air supplied to each floor was measured on a daily basis. A voluntary questionnaire was circulated to all staff to detect any changes in personal smoking habits over the course of the study.

Results of the investigation showed statistically significant reductions of RSP and CO concentrations on the test floor. After standardization to the control floor, the test floor results indicated a reduction of RSP and CO, 23% and 7.2%, respectively. (TDSA, 3-1073; PM, 3-1074)

In 1989, Proctor and co-workers examined nicotine, respirable particulates, carbon monoxide, carbon dioxide, and volatile organics in the air of smokers' and nonsmokers' offices.[28] The data suggest very little nonsmoker exposure to various PTS constituents. The median UV-PM (ultraviolet particulate matter) level in nonsmokers' offices was 8.8 ug/m³; the median nicotine value was 0.6 ug/m³. Carbon monoxide and carbon dioxide levels did not differ appreciably between smokers' and nonsmokers' offices. Overall, levels of volatile organics did not differ significantly between smokers' and nonsmokers' offices. (PM, 3-1074)

Bayer and Black (1987) reached a similar conclusion in their investigation of VOC levels in smokers' and nonsmokers' offices.[49] They noted that although differences in nicotine concentrations were measured for offices of smokers and nonsmokers, no significant differences in VOC levels were discerned in smokers' vs. nonsmokers' offices. The researchers observed that "it was not possible" to correlate VOC concentrations with PTS or to attribute the source of various VOCs to PTS. (PM, 3-1074)

Recent studies on PTS constituent levels aboard commercial aircraft, including a 1989 study performed for the U.S. Department of Transportation, indicate the effectiveness of simple separation of smokers and nonsmokers in the minimization of PTS exposures.[93,94,95] (PM, 3-1074)

Similarly, Proctor (1987) monitored PTS constituents before and after a smoking ban on public transportation in the United Kingdom.[96] While nicotine concentrations decreased from 7 ug/m³ (micrograms per cubic meter) to 3 ug/m³ in nonsmoking compartments after the ban, particulate and CO levels remained unchanged. This suggests that PTS contributions to levels of particulates and CO in public transportation are not significant. (PM, 3-1074)

Investigators from Healthy Buildings International recently summarized results of a paper entitled "The Measurement of Environmental Tobacco Smoke in 585 Office Environments."[41] Using nicotine and particulates as markers for the presence of PTS, the investigators developed a computer model to predict whether a given set of constituent data came from a smoking or nonsmoking area. Using the constituent measurements from a given area, the computer model identified with 96 percent accuracy whether or not the area was "nonsmoking." This is, "spillover" of tobacco smoke was reported in only 4 percent of the areas. As the authors concluded:

> This finding shows that, in general, conventional office ventilation and partitioning is successful in separating smokers from nonsmokers.

And:

> Discriminant analysis shows that when 'blindfolded' for presence or absence of smokers, in most cases realistic smoking levels do not significantly influence the aspects of air quality that were measured, and spillover from smoking areas into nonsmoking areas appears to be minimal. This work further reinforces the position the American Society of health Refrigerating and Air Conditioning Engineers (ASHRAE) has taken on ETS in office buildings in ASHRAE Standard 62-89 (1989), in that acceptable air quality can be maintained in properly ventilated offices with

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a moderate amount of smoking, even without smoker segregation. (HBI, 3-1053)

The studies reviewed above contain data regarding the low levels of PTS constituents purportedly "transferred" from smoking to nonsmoking areas, even under conditions involving a shared ventilation (recirculation) system. Data reported in those studies indicate that PTS constituents, and particularly nicotine, RSPs, and CO in nonsmoking areas in buildings where smoking is permitted, are often only slightly above the limits of detection, and often indistinguishable from "background" levels of such constituents which can be found in buildings in which smoking is altogether prohibited. The data support the contention that simple separation of smokers and nonsmokers effectively reduces PTS exposure in nonsmoking areas even under conditions of recirculation.

Dedicated Smoking Lounges and Other Options

Research thus indicates that compliance with ventilation rates comparable to those prescribed by ASHRAE 62-1981 and/or simple separation of smokers and nonsmokers in the workplace will effectively minimize exposure of nonsmokers to PTS constituents. Nevertheless, some employers have deemed it necessary to physically separate smokers and nonsmokers, typically by establishing a room or lounge dedicated to smoking. The cluster of smokers in a confined space, however, may place excessive demands upon an existent ventilation system. Thus, separate smoking rooms are often equipped with independent ventilation and/or exhaust systems.

ASHRAE suggests a ventilation rate of 60 cfm/person for areas dedicated as smoking lounges. In order to preclude the "migration" of tobacco smoke from the lounge into the central ventilation system, the lounge may be fitted with a exhaust to the exterior. Equipping a room with a separate ventilation and exhaust system, however, can be very costly to property owners and building managers. Indeed, a provision of a separate ventilation/exhaust for dedicated smoking areas may not be feasible because of such cost constraints, particularly for smaller businesses.

Existing technology permits partial recovery or at least minimization of increased costs due to retrofit and operation expenditures for separate smoking lounges. One such technological advance utilizes the Energy Recovery Unit (ERU), the principal for which involves the passing of air exhausted from the smoking lounge across a heat recovery wheel which then transfers the heat from the lounge to the wheel. The wheel then rotates from the exhaust air stream to the incoming supply air stream. On cold days, for example, the incoming air is heated and on warm days it is cooled. Energy recovery efficiencies have been estimated between 70 to 80 percent for such units, thereby substantially reducing operating costs incurred by increasing ventilation for a designated smoking area.

Another technological advance, discussed in OSHA RFI 3-879, involves the use of the "cold air distribution system." Such systems also make use of an "enthalpy" or heat-transference wheel used in the ERU. When properly designed, installed, and operated, the cold air distribution system permits delivery of fresh air at ASHRAE specified rates and energy costs which are far below those of traditional HVAC systems.

Another option for the ventilation system of a dedicated smoking lounge involves displacement or "plug flow" ventilation, in which ventilation (supply) air flows through the floor and moves vertically through the room and is exhausted at the ceiling. Substances present in the indoor environment such as dust, tobacco smoke, odors, bacteria, etc., will rise vertically above the room and will be removed by the exhaust. (PM, 3-1074)

All of the options listed above would require additional expenditures for retrofit, as well as increased operation costs. The options are available for those who desire to physically segregate smokers and nonsmokers in the workplace. However, no data exist, to our knowledge, which suggest that the dedicated smoking lounge will significantly reduce exposure to PTS-related constituents beyond reductions achieved by appropriate ventilation and the simple separation of smokers from nonsmokers. Indeed, data from numerous studies submitted to the RFI docket and discussed in this brief indicate that the PTS constituent burden in areas that are adequately ventilated and/or simply

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segregated from smoking is minimal, with constituent levels barely above detection limits for sensitive monitors, and often otherwise indistinguishable from the air in completely "smoke-free" buildings. Thus, the submission from R.J. Reynolds observes:

> Any assessment of the need for measures to supplement a generic standard with special provisions such as mandated smoking lounges with separate exhaust or a smoking ban to reduce further any residual levels of PTS would plainly reveal that such measures would only result in an insubstantial reduction of an already *de minimis* exposure level. Accordingly, the imposition of such measures as mandated smoking lounges or smoking bans would be impermissible under this Supreme Court's direction that OSHA is authorized only to eliminate significant risks and may not seek the 'regulation of insignificant risks.' (3-1086)

Smoking Policies Conclusion

A requirement that all buildings which permit smoking must have designated smoking areas with separate ventilation and exhaust would be a costly requirement and clearly superfluous, given the scientific data regarding the simple separation of smokers and nonsmokers. Moreover, retrofit costs required for a designated area with separate air intake and exhaust could be economically burdensome to an employer or building owner.

Workplace environments are infinitely varied and smoking policies therefore need to be designed to fit the requirements of individual workplaces. The question of "feasibility" ought to be determined on an individual, case-by-case basis. In certain workplaces, it may be unnecessary to institute any change in current employer smoking policies. In others, minimal changes may sensibly accommodate the interests of the employer and smokers and nonsmokers alike.

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SUMMARY

Substantive comments submitted in response to the OSHA RFI support the building systems approach to indoor air quality. The approach is supported in both theory and practice, and it has been used successfully for the mitigation of indoor air quality problems.

The building systems approach offers a *comprehensive* solution to poor indoor air quality. Attention to adequate supply air and its distribution to occupied spaces, together with proper maintenance of the HVAC system, provides a means for decreasing exposure to a wide range of substances in indoor air — a solution which remains constant over time.

The approach is *feasible* because it relies upon already existent technology and currently adopted consensus standards for ventilation. It is also *cost-effective* because an increase in outdoor air ventilation, for example, does not necessarily adversely affect annual energy budgets, and it may lead to a reduction in complaints and/or increased worker productivity.

We therefore urge OSHA to carefully consider the merits of the building systems approach during its review process.

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